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ON THE CORRELATION BETWEEN ROTATIONAL VELOCITIES OF THE COMPONENTS OF VISUAL BINARIES

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RESUMEN

La existencia de correlación estadística entre las velocidades de rotación de las componentes de binarias visuales es nuevamente discutida. Para las binarias cuyas componentes pertenecen a las clases de luminosidad IV y V, y son además de tipos espectrales iguales o similares, se reafirma la existencia de dicha correlación. Se propone además una posible explicación de este hecho.

ABSTRACT

The existence of a statistical correlation between the rotation velocities of the components of visual binaries is rediscussed. For the binaries whose components belong to the luminosity classes IV and V, and have also equal or similar spectral types, the existence of such a correlation is confirmed. In addition, a possible explanation of this fact is proposed.

Key words: ROTATIONAL VELOCITY — VISUAL BINARY.

I. INTRODUCTION

The study of the rotational velocities of the components of binary systems is of great interest, because it is of fundamental importance for a better understanding of the origin and evolution of such systems. The tendency towards synchronism between the orbital revolution and the axial rotation periods in close binaries (CB) is a fact established for a long time (Plaut 1959; Levato 1974). It is currently accepted that this is due to the action of tidal braking. In effect, for stars of the Main Sequence and spectral types in the range B0-F0, we observe that the mean rotational velocities of the CB components are sensibly smaller than those corresponding to single stars (Levato 1974).

With respect to the visual binaries (VB) several authors have found a correlation between the projected rotational velocities of the components (Steinitz and Pyper 1970; Bernacca 1972). More recently Levato (1974) has reaffirmed the existence of the correlation analyzing a VB sample much larger than the one used by the above mentioned authors (correlation coefficient found $r = 0.35$; size of the sample $N = 104$ pairs).

II. DISCUSSION ON THE EXISTENCE OF SUCH CORRELATION

We will take into account the list of 104 VB used by Levato in the above mentioned paper, and published by the same author separately (Levato 1975). These pairs, taken fundamentally from Slettebak (1963) and his own observations, were selected by the author according to the following criteria: components of luminosity classes IV and V, spectral types earlier than F2, including also A_m, A_p, B_p, B_e stars and SB1 binaries. The VB have been represented in the diagram $x_1 = V_1 \sin i_1$, $x_2 = V_2 \sin i_2$, that correspond to the projected rotational velocities of the primary and the secondary respectively (Figure 1).

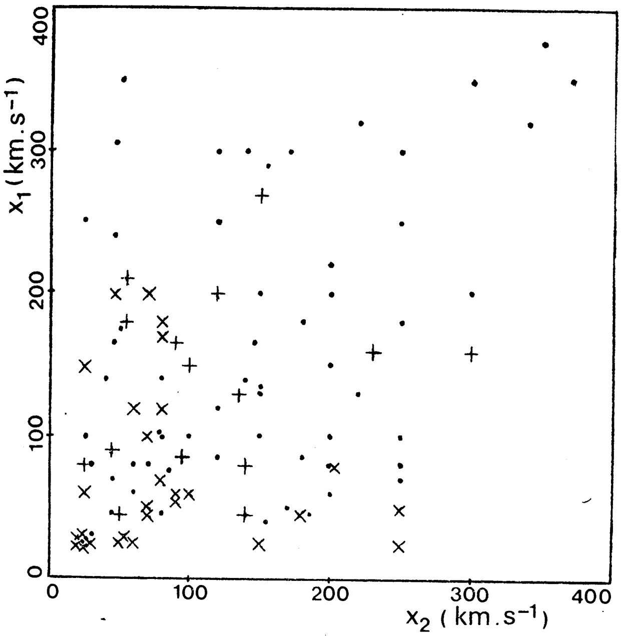

FIG. 1. Distribution of VB in the diagram (x_1, x_2). We show: VB whose components do not differ by more than five subclasses in their spectral types (dots); VB that differ by more than five (plus signs) and that contain at least one A_p or A_m (crosses). For the first group we obtain a correlation coefficient $r = 0.398$ and a regression line $x_1 = 0.33x_2 + 91.9$.

In accordance with the characteristics of the VB sample, we have decided to group them into three categories: a) those whose components do not differ by more than five subclasses in their spectral types; b) those with a difference of more than five; and c) those consisting at least of an A_m or A_p star. The latter would be, in fact, evolved stars of slow rotation (van den Heuvel 1968). For the a) group (61 pairs) we obtained a correlation coefficient $r = 0.398$. According to the Student *t*-test, for the size of the sample considered, such a coefficient is significant even at the 0.5% level. On the other hand, for the b) group (15 pairs) and the c) group (23 pairs) we obtained coefficients close to zero: $r = 0.232$ and $r = 0.108$ respectively.

III. ORIGIN OF THE ROTATIONAL CORRELATION

A possible explanation of the existence of the rotational correlation could be found by assuming that VB's are formed by the fission of a rapidly rotating protostar (see, *e.g.*, Ostriker 1970). However, whereas this mechanism could describe the formation of CB, it presents difficulties in explaining satisfactorily the formation of widely separated pairs.

A mechanism suggested for the formation of the binaries of wide separation calls for a capture during the dissolution of a cluster or association (see *e. g.*, Huang 1968). The formation of a binary or multiple systems, as a consequence of the dynamical evolution of clusters, was a result of the work of several authors by means of numerical studies with models (Hayli 1971; Wielen 1974).

If the origin of such systems is due to capture: how does one explain the correlation found?. Abt (1970) has shown that in galactic clusters there is, for the more luminous members, a bimodal distribution of the projected rotational velocities x = Vsini with two characteristic group: 1) slow rotators and 2) rapid rotators, showing in many cases a prevalence of one of them. According to the author, the prevalence of group 1) or 2) would correspond with the greater or smaller frequency of CB in the cluster. The pairs formed by random capture inside clusters with stars showing distribution of x with the above mentioned characteristics, would have a high probability to be composed of two components either of high or low rotational velocity, in accordance with the group that prevails inside the cluster. Then, it is to be expected that in a VB sample we must find many pairs with similar rotation velocities if, according to what was previously seen, they were formed by capture during the dissolution of the open clusters they originally belonged to. In this way, we can account for the observed correlation in VB with components of the same or similar spectral type, which is precisely one of the conditions fulfilled by the distributions for the cluster stars referred to by Abt.

The distribution of projected rotational velocities, for stars of luminosity classes IV-V and certain spectral type ranges, of some galactic clusters and associations, are shown in Figure 2. Also the distribution of main sequence single stars for the range B5-B9 (taken from Deutsch 1970), is shown. This author obtained that distribution by assigning a bimodal Maxwellian distribution to the equatorial rotational velocities V of the single stars. According to Deustch, the excess of slow rotators in such a distribution is due fundamentally to the presence of evolved CB

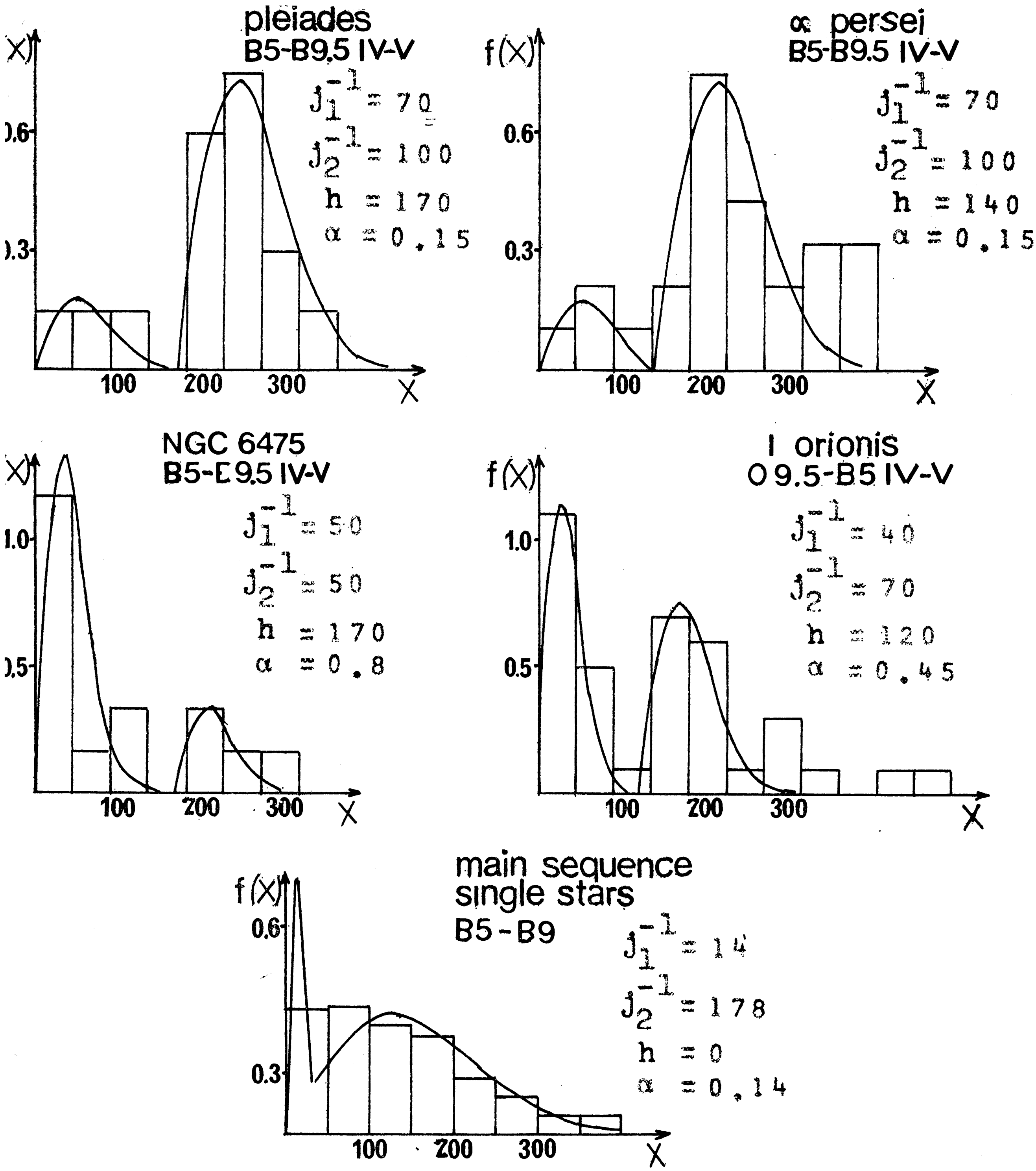

FIG. 2. Distribution of the projected rotational velocities $x = V\sin i$ for single field stars of the main sequence and certain clusters and associations. Beside each diagram the spectral types of the stars considered in the histogram and the values of the parameters j_1, j_2, h and α for the adjusted functions f(x) are included. f(x) is given in percentage/km s^{-1} ; x, j_1, j_2 and h in km s^{-1}. In each case we have taken into account the following number of stars: Pleiades: 15 ; α Persei: 25 ; NGC 6475 : 12 ; I Orionis: 37 and Main Sequence Stars: 251. The histograms for the cluster Pleiades, α Persei and NGC 6475 have been taken from Abt (1970), I Orionis from Abt and Hunter (1962) and the histogram and distribution function for the single stars from Deutsch (1970).

where the primary has accreted its mass from its companion. In this sense the conclusion regarding the incidence of CB in relation to the greater or lesser proportion of the slow rotator group is similar to the one given by Abt for the cluster stars. We have adopted the bimodal maxwellian distribution for the cluster stars with the modification imposed by the introduction of a parameter h for the rapid rotators, obtaining:

$$f(x) = \alpha j_1 \phi(j_1 x) + K(1-\alpha) j_2 \phi[j_2(x-h)], \quad (1)$$

being

$$\phi(z) = 2z \exp(-z^2),$$

where the coefficient $\alpha \leq 1$ and $K = 1$ for $x \geq h$ and $K = 0$ for $x<h$. The parameters j_1 and j_2 are the inverse of the rms projected rotational velocities $j^{-1} = [<x^2>]^{1/2}$ and we assume that they are constant within a certain range of spectral types. The first term refers to slow rotators while the second, to the rapid rotators. As we see in Figure 2, the correspondence between the observed distributions in the clusters, as given by the histograms, and the theoretical ones, given by Eq. (1) are satisfactory.

Now we can analyse the problem from another point of view: let $u = x_1 - x_2$ be the difference between the projected rotational velocities of the VB components. We assume $x_1 \geq x_2$.

For a cluster, in particular, if the VB are formed by the random combination of two stars of projected rotational velocities x_1 and x_2, we have:

$$F(x_1, x_2)dx_1dx_2 = f(x_1)f(x_2)dx_1dx_2. \quad (2)$$

It must be remarked that although this relation implies independence between x_1 and x_2, the correlation between these variables does show up when we consider pairs from several clusters, while this relation was applied to a single cluster.

Replacing $x = x_1 - u$ in Eq. (2) we have:

$$F'(x_1, u)dx_1du = f(x_1)f(x_1-u)\frac{\partial x_2}{\partial u}dudx_1. \quad (3)$$

The distribution function of u, $\psi(u)$, is obtained by integrating Eq. (3) with respect to x_1, for the interval $u \leq x_1 \leq x_M$, where x_M is the maximum projected rotational velocity

$$\psi(u)du = du \int_u^{x_M} f(x_1)f(x_1-u)\frac{\partial x_2}{\partial u}dx_1. \quad (4)$$

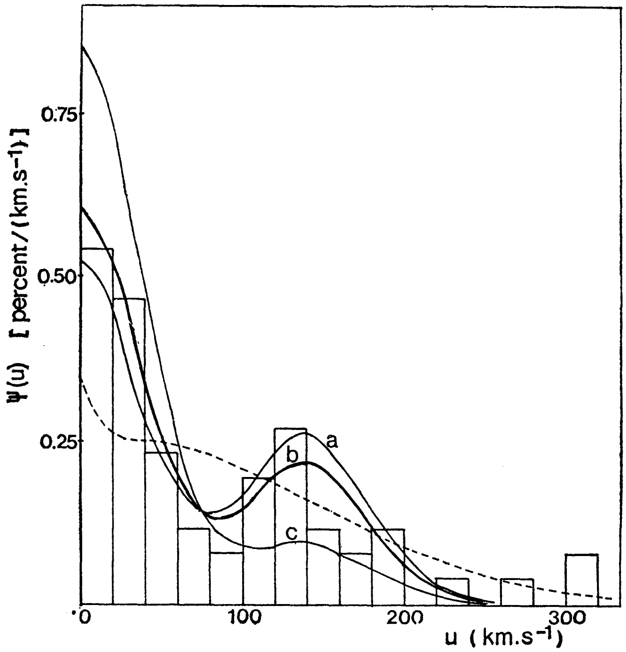

FIG. 3. Distribution of the u differences between the projected rotational velocities of the VB components. These do not differ by more than five subclasses in their spectral types. The histogram was obtained with the VB in the (61 pairs) sample studied taking 20 km s^{-1} intervals for u. The distribution functions a, b and c were obtained from distributions f(x) of the projected rotational velocities that are shown in Figure 4 with correlative letters. The dashed curve corresponds to the distribution function of the single field stars from Figure 2. We notice for the b curve a good agreement to the observed distribution.

For calculation purposes, we adopt $x_M = 450$ km s^{-1}. In Figure 3 the observed distribution of u for the VB sample given by Levato is compared with some theoretical distributions. We took into account the 61 pairs whose components do not differ by more than five subclasses in their spectral types. The calculated distributions have been obtained by solving numerically Eq. (4) for the distribution f(x) given by Deutsch for the single field stars, and different f(x) cluster type distributions as given in Figure 4. As can be seen, the distribution calculated for single field stars (dashed curve) is appreciably different from the observed one. On the other hand, we notice a close agreement between the observed distribution and the curve b corresponding to a cluster having a distribution f(x) with: $j_1^{-1} = j_2^{-1} = 60$ km s^{-1}, h = 140

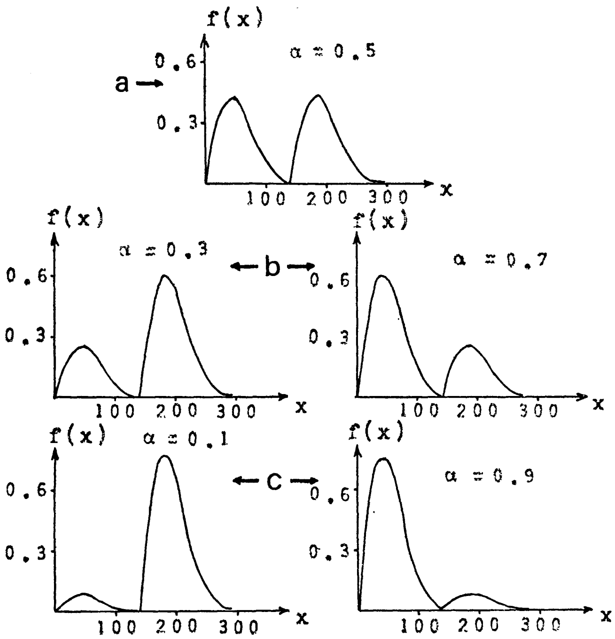

FIG. 4. Distribution functions f(x) of the type observed in clusters and associations. f(x) is given in percentage/km s^{-1} and x in km s^{-1}. We have adopted for the parameters the following values: $j_1^{-1} = j_2^{-1} = 60$ km s^{-1}; h = 60 km s^{-1} and a value for α that is attached to each group.

km s^{-1} and $\alpha = 0.3$ or $\alpha = 0.7$, that is a 30% of the rapid rotators group versus 70% of slow rotators or viceversa, that is, a proportion that may be considered characteristic for many clusters and associations. Also, by means of the f(x) cluster type distributions, we explained satisfactorily the secondary maximum that appears in the observed distribution of u for u = 130 − 140 km s^{-1}.

IV. CONCLUSIONS

1. The existence of a certain correlation between the projected rotational velocities of the VB components is confirmed only when these belong to luminosity classes IV and V and to equal or similar spectral types.

2. In constrast to what happens with the CB, for the VB we do not notice an appreciable difference between the mean rotational velocities of their componentes with those corresponding to the single field stars (Slettebak 1963; Levato 1974). This suggests that the rotational velocities of the VB components do not suffer any alteration due to the presence of the companion.

3. The correlation found does not reject the possibility of the VB being formed by capture during the process of dissolution of galactic clusters or associations. The good agreement found between the observed distribution of u for the VB sample and the distribution function $\psi(u)$, deduced from the distribution of rotational velocities typical of clusters, gives support to this point of view regarding the formation of such systems.

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